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(54) Method and system for detection of nitrogenous explosives by using nuclear resonance absorption.

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(73) Proprietor: **THE STATE of ISRAEL Atomic Energy Commission Soreq Nuclear Research Center**
Nahal Soreq
Yavne 70 600(IL)

(72) Inventor: **Vartsky, David**
14/3, Pinsker St.
Rehovot(IL)
Inventor: **Goldberg, Mark**
16, Hanasi Harishon St.
Rehovot(IL)
Inventor: **Breskin, Amos**
3, Taran St.
Rehovot(IL)
Inventor: **Engler, Gideon**
5, Hahita St.
Rehovot(IL)
Inventor: **Goldschmidt, Aharon**
30A Jabotinsky St.
Nes Ziona(IL)
Inventor: **Izak, Ephraim**
15, Trechtenberg St.
Rishon Le-Zion(IL)
Inventor: **Even, Ovadia**
12, Idmit St.
Givataim(IL)

(74) Representative: **VOSSIUS & PARTNER**
Postfach 86 07 67
D-81634 München (DE)

Rank Xerox (UK) Business Services
(3.10/3.09/3.3.3)

Description

The present invention concerns a method and system for detection of nitrogenous explosives by using nuclear resonance.

The detection of explosives has become a highly important issue in recent years, especially because of the increasing occurrence of terrorist activities all over the world. Searching for explosives by security personnel is nowadays a matter of course in many public places and installations such as airports, government edifices, army and police installations and the like. In many instances such searches are carried out by manual inspection of people's belongings and may occasionally also involve the employment of dogs trained to sniff explosives. It is also customary to X-ray personal belongings in order to detect suspicious objects; but generally, indications obtained in this way are considered inconclusive and as a rule, when something suspicious is detected a follow-up manual inspection is required.

US-A-3 832 545 discloses a method of detecting nitrogenous materials in objects, such as luggage and parcels, in which gamma rays due to neutron activation are detected.

Nuclear resonance fluorescence is a process in which a nucleus is raised to an excited state by absorbing an incident photon. The excited nucleus may decay by emission of either a photon -(γ,γ) reaction known as nuclear resonance scattering (NRS) or by a particle emission, e.g. a (γ,p) reaction. Such decay or de-excitation is characterized by the emission of γ-radiation of specific energies which correspond to certain discrete energy levels of the atomic nucleus and which are atom-specific. Consequently in NRS it is possible to detect a given substance in a mixture by irradiating the mixture with γ-rays having an energy that corresponds to the energy level to which the sought-after atom could be excitable. If that atom is present in the mixture there occurs a resonant absorption which in turn produces fluorescence detectable by photon detectors that are in common use.

The main use of NRS is in research, e.g. for determining half-lives of excited nuclear states of various atoms, but some analytical methods based on NRS were developed for application in medicine, e.g. for detection of excessive amounts of iron in the liver, and also in the mineral industry, e.g. for detection of copper and nickel in minerals. These methods are, however, inapplicable in detecting nitrogenous explosives since the partial electromagnetic widths for ground state transitions from most excited states of nitrogen is very low and, therefore, NRS thereof is barely detectable.

In accordance with the invention it has been found that as distinct from NRS, nuclear resonance absorption (NRA) is suitable and effective for the detection of nitrogen concentrations in inspected objects. In this method the transmitted portion of the incident photon flux is measured, rather than the scattered flux as in NRS. This approach enables the recording of spatial information and may therefore be called resonant radiography.

The probability (cross-section) for excitation of a nucleus by photons as function of photon energy, exhibits resonant behaviour, i.e. it is largest when the energy of the incident photon corresponds to the excitation energy of the nuclear level. Each nuclear level has a specific cross-section for absorbing the incident photon depending on level parameters such as energy, partial width of direct γ-transition to the ground state - $\Gamma_{\gamma o}$, total width of the level Γ_T, angular momentum and doppler width - Δ. In general, a nuclear level can be applied to nuclear resonant radiography if the following conditions are met:

$$\text{The ratio } \Gamma_{\gamma o}/\Gamma_T \geq 0.01$$

$$\text{The ratio } \Delta/\Gamma_T \ll 1$$

Investigations conducted in accordance with the present invention revealed that in nitrogen (^{14}N) only the properties of the 9.17 MeV level are such that the absorption cross-section is adequate for resonant absorption radiography. In practice, the resonant component of attenuation in nitrogen, if present, is superimposed on the non-resonant attenuation, which is undergone by γ-rays in all materials. Experimentally, the two quantities directly determined are the total attenuation (resonant and non-resonant) and the non-resonant component. The net resonant attenuation, which is the quantity underlying the present invention, is extracted from these two quantities and is indicative of the amount of nitrogen traversed by the γ-rays. For the 9.17 MeV level the net resonant attenuation in nitrogenous explosives is about 2% per centimeter of explosive.

It has further been found in accordance with the present invention that the net resonant attenuation is readily detectable by a conventional γ-ray detector provided the detection medium therein contains nitrogen. Such a detector, which may be described as a resonant detector, selects the relevant energy portion of the transmitted flux spectrum which contains the resonant absorption information.

Based on all this, the present invention provides a method and a system for the detection of a nitrogenous explosive material in an object with the features of the claims.

The spatial distribution data may be processed and interpreted in terms of the presence or absence of explosives and/or benign nitrogen-containing materials within the inspected object.

The net resonant component of attenuation is directly proportional to the amount of nitrogenous explosive present in the inspected object. Preferably the attenuation is computed automatically by a suitable comparator device of known design and the output of such a device may be so calibrated as to give directly quantitative indications of the amount of explosives in the object.

For scanning the inspected object the said holder means may be movable whereby the inspected object is gradually shifted through the γ-ray beam in such a way that the entire cross-section thereof is successively exposed. This may be accomplished by associating the above system with mechanical means such as a conveyor belt for continuously or intermittently feeding and removing objects to be inspected.

Alternatively the emitter and detector may be moved synchronically so that the beam suitably scans the object.

In accordance with one embodiment the above system comprises processor means for continuously comparing the detected photon flux with the emitted photon flux. If desired, such processor means may be adapted to interpret any flux modulations obtained by scanning an object.

In the following some specific embodiments of the invention will be described with reference to the annexed drawings in which:

Fig. 1 is a diagramatic illustration of a system according to the invention;

Figs 2a - 2d are graphical representations in which the cross-section for absorption, incident flux, transmitted flux and detection efficiency are plotted against energy;

Fig. 3 is a block diagram of a system according to the invention; and

Fig. 4 is a diagrammatic illustration of an experimental model arrangement for showing the feasibility of the NRA method according to the invention.

The method according to the invention is best explained with reference to Fig. 1. As shown, a γ-ray source 1 emits γ-rays of a desired and monitored flux, symbolized by line 2, so as to impinge on a γ-ray detector 3 electrically linked to a recorder 4. Detector 3 is designed to produce electric signals in response to incident γ-rays and any current modulations are recorded and displayed by recorder 4.

An object 5 held by means of suitable holder means (not shown) is successively moved across beam 2. The object 5 is shown to contain a body of a nitrogenous explosive 6. As long as body 6 does not intersect beam 2 the gamma rays pass across the object without any resonant attenuation. Once however, body 6 crosses beam 2 the resonant flux detected by detector 3 is attenuated and the information is transmitted to recorder 4.

In the performance of the method according to the invention the object 5 is gradually passed across beam 2 so as to be scanned thereby. This may be achieved either by moving the object itself or else by synchronically moving emitter 1 and detector 3.

An ideal γ-ray source for the purpose of the present invention would be a source which emits photons that are all concentrated in a 200 electron volt energy interval around the peak of 9.17 MeV so that all of them undergo resonant attenuation in case the inspected object contains a nitrogenous explosive. However such sources are not available and in order to count only resonant photons of 9.17 MeV out of the transmitted fraction of the radiation, one has to use a resonant detector which is sensitive only to photons in the 9.17 MeV±100 eV interval.

Source 1 may for example be a device which emits photons upon capture of 1.75 MeV protons in ^{13}C. This source of 9.17 MeV photons is the closest to the ideal γ-source since the γ-rays emitted at a given angle upon the capture of the protons are monochromatic (doppler shifted but not broadened). In order to construct such a source for an operational facility one needs a proton accelerator capable of delivering a proton current of about 1 mA.

An alternative device that may be used is the so-called high energy bremsstrahlung source which is commercially available. This radiation source is an electron accelerator capable of producing a broad spectrum of energetic photons. The fraction of resonant photons which can be obtained with such a source is very small (about 5 orders of magnitude smaller than with the previously described source) but accelerators with adequate intensity are readily available.

In detector 3 which, as mentioned above,should hold a nitrogen-rich detection medium, the incident photons react resonantly with the nitrogen medium via the (γ,p) reaction. The resulting 1.5 MeV protons have then to be counted with high discrimination against the numerous compton electrons produced in the detector by photons of all energies.

Two types of detectors may be mentioned. The first are gas detectors (proportional counters or gas scintillators) filled with nitrogen gas. In these detectors the discrimination between the protons and electrons is made by the amount of energy left by the particles in the detector. By limiting the dimensions of the chamber to the range of the 1.5 MeV protons one can ensure that electrons deposit in the counter no more than 50 keV.

The second kind of detectors are scintillators with a liquid detection medium. An adequate resonant liquid scintillator may be made by adding nitrogen-containing compounds to existing liquid scintillators or by using exclusively a scintillating material which contains nitrogen as a constituent of its molecule. Since in these detectors the resonant scintillating medium is denser than in the gas detectors, they are more efficient for detecting γ-rays. Upon interaction with radiation they emit light. The discrimination between protons and electrons is possible on the basis of the difference in the decay time of the produced light, the light produced by protons having a larger decay constant. The commercially available liquid scintillators have organic solvents such as xylene or toluene as scintillation medium. No scintillators with a nitrogenous medium are commercially available, but have been produced in our laboratory.

The cross-section for absorption of a photon by a nitrogenous absorber such as a nitrogenous explosive has a resonance shape at 9.17 MeV as shown in Fig. 2a which plots the cross-section for absorption against energy. In Fig. 2b the incident flux is plotted against energy and in Fig. 2c the transmitted flux is plotted against energy. From these two figures it is readily seen that the portion of incident photon flux in the specific energy interval corresponding to the 9.17 MeV excited state will undergo nuclear resonant absorption whenever the beam encounters a region of high nitrogen concentration in the inspected object. This effect can be quantitatively measured by means of an appropriate detector with a resonant response as specified above and as shown in Fig. 2d which plots the detection efficiency against energy. The detection efficiency which is at its peak in the 9.17 MeV range, drops rapidly to zero on both sides.

As explained above, NRA requires resonant detectors to select the relevant energy portion of the transmitter flux spectrum which contains the resonant absorption information. In accordance with the invention γ-ray detectors with nitrogen rich detection medium fulfil that function. Since, however, in addition to the resonant attenuation there also occurs a conventional non-resonant attenuation, non-resonant detectors, e.g. NaI or Bismuth Germanium detectors, are required in order to factor-out this component in the spectrum which is then used for normalization purposes.

Fig. 3 shows a block diagram of an installation according to the invention with resonant and non-resonant detectors. As shown, the system comprises a γ-ray emitter 7 serving as photon source and linked to a flux monitor 8. There are further provided collimator blocks 9 and 10 for the collimation of the γ-radiation emitted from source 7 in front of and behind the inspected object. The system further comprises an array 11 of resonant detectors and an array 12 of non-resonant detectors, both linked to a data analysis and display device 13 which is also linked to the flux monitor in a manner not shown.

The system is associated with a conveyor 14 adapted to move successively a plurality of objects such as object 15 across the beam emitted by photon source 7. After its encounter with an object 15 the passing radiation is once more collimated by collimator lens 10 and is thereupon analysed by the assembly of resonant detectors 11, non-resonant detectors 12 and data analysis devices 13.

Instead of non-resonant detectors, it is also possible in accordance with the invention to make use of Compton electrons produced in the resonant detector by photons of all energies for factoring out the non-resonant attenuation component.

The feasibility of the NRA method according to the invention was demonstrated in the laboratory using thin melamine absorbers (67% nitrogen). The resonant detector was laboratory-made and consisted of a commercially available liquid scintillator (NE-213), mixed with acetonitrile (34% nitrogen). The nitrogen content of the mixture was 10% wt/wt.

The experimental arrangement is shown in Fig. 4. The melamine absorber was mounted on a conveyor and was inserted in and out of a 9.17 MeV γ-ray beam. The non-resonant attenuation was measured by a 6"x6" NaI detector positioned behind the resonant detector. The following Table summarizes the results obtained in the experiment.

Melamine thickness (cm)	Net resonant attenuation (%)
0	0.6 + 1.3
1.2	3.2 + 1.2
2.4	7.6 + 1.5

This demonstration shows that given sufficient statistical precision, it is possible to detect thin absorbers significantly and quantitatively. However, for higher sensitivity scintillators with solvents of higher nitrogenous content should be used.

Claims

1. A method for the detection of a nitrogenous explosive material (6) in an object (5), comprising:

i) placing on one side of the object a source (1) for 9.17 MeV γ-rays adapted to produce a desired emitted photon flux (2);

ii) placing on the opposite side of the object a γ-ray detector (3), or array of detectors, with a nitrogen rich detection medium;

iii) scanning the object (5) with a γ-ray beam (2) from said source;

iv) reading from said γ-ray detector (3) or array of detectors the total and the non-resonant attenuations of the incident photon flux; and

v) deriving from said attenuations the net resonant attenuation and the spatial distribution thereof.

2. A method according to Claim 1 comprising interpreting the said net resonant attenuation to derive a quantitative reading of any detected nitrogen.

3. A system for the detection of a nitrogenous explosive (6) material in an object (5), comprising:

i) a source (1) for 9.17 MeV γ-rays;

ii) a γ-ray detector (3) with a nitrogen-rich detection medium and adapted to show modulations of the detected photon flux;

iii) holder means for holding an inspected object so as to intersect the γ-rays from said source for 9.17 MeV γ-rays; and

iv) means for scanning the inspected object with the γ-rays emitted by said source for 9.17 MeV γ-rays.

4. A system according to Claim 3 in which said holder means are movable whereby an inspected object is scanned by the γ-rays.

5. A system according to Claim 4, wherein said holder means is a conveyor belt (14) adapted to move a succession of objects for inspection across the γ-rays.

6. A system according to Claim 3 in which the γ-ray source and detector are movable synchronically whereby an inspected object is scanned by the γ-rays.

7. A system according to any one of Claims 3 to 6, comprising processor means (13) for continuously comparing the detected photon flux with the emitted photon flux.

8. A system according to Claim 7, wherein said processor means are adapted to interpret any flux modulations obtained by scanning an object.

Patentansprüche

1. Verfahren zum Nachweisen eines stickstoffhaltigen Sprengstoffmaterials (6) in einem Gegenstand (5) mit:

i) Anordnen einer zur Erzeugung eines gewünschten emittierten Photonenflusses (2) geeigneten Quelle (1) für 9.17 MeV γ-Strahlen an einer Seite des Gegenstands;

ii) Anordnen eines γ-Strahlen-Detektors (3) oder einer Gruppe von Detektoren mit einem stickstoffreichen Detektormedium an der gegenüberliegenden Seite des Gegenstands;

iii) Abtasten des Gegenstands (5) mit einem γ-Strahl (2) von der Quelle;

iv) Ablesen der gesamten und der nichtresonanten Schwächung des auftreffenden Photonenflusses vom γ-Strahlen-Detektor(3) oder von der Gruppe von Detektoren; und

v) Herleiten der rein resonanten Schwächung und deren räumlicher Verteilung aus den Schwächungen.

2. Verfahren nach Anspruch 1 durch Auswerten der rein resonanten Schwächung, um ein quantitatives Ablesen des nachgewiesenen Stickstoffs zu erhalten.

3. System zum Nachweisen von stickstoffhaltigem Sprengstoffmaterial (6) in einem Gegenstand (5) mit:
i) einer Quelle (1) für 9.17 MeV γ-Strahlen;
ii) einem γ-Strahlen-Detektor (3) mit einem stickstoffreichen Detektormedium, der dazu geeignet ist, Modulationen des festgestellten Photonenflusses anzuzeigen;
iii) einer Halteeinrichtung zum Halten eines untersuchten Gegenstandes, um den Gegenstand mit den γ-Strahlen von der Quelle für 9.17 MeV γ-Strahlen zu überschneiden; und
iv) einer Einrichtung, zum Abtasten des untersuchten Gegenstands durch die von der Quelle für 9.17 MeV γ-Strahlen emittierten γ-Strahlen.

4. System nach Anspruch 3, wobei die Halteeinrichtung beweglich ist, wodurch ein untersuchter Gegenstand durch die γ-Strahlen abgetastet wird.

5. System nach Anspruch 4, wobei die Halteeinrichtung ein Transportband (14) ist, durch das eine Reihe von zu untersuchenden Gegenständen durch die γ-Strahlen bewegt wird.

6. System nach Anspruch 3, wobei die γ-Strahlen-Quelle und der Detektor synchron bewegbar sind, wodurch ein untersuchter Gegenstand durch die γ-Strahlen abgetastet wird.

7. System nach einem der Ansprüche 3 bis 6 mit einer Verarbeitungseinrichtung (13) zum kontinuierlichen Vergleichen des festgestellten Photonenflusses mit dem emittierten Photonenfluß.

8. System nach Anspruch 7, wobei die Verarbeitungseinrichtung geeignet ist, die durch das Abtasten eines Gegenstands erhaltenen Flußmodulationen auszuwerten.

Revendications

1. Procédé pour la détection d'une matière explosive azotée (6) dans un objet (5), comprenant les étapes consistant à :
i) placer sur un côté de l'objet une source (1) pour des rayons γ de 9,17 MeV destinée à produire un flux émis désiré de photons (2);
ii) placer sur le côté opposé de l'objet un détecteur de rayons γ (3), ou un réseau de détecteurs, avec un milieu de détection riche en azote;
iii) balayer l'objet (5) avec un faisceau de rayons γ (2) provenant de ladite source;
iv) lire à partir dudit détecteur de rayons γ (3) ou du réseau de détecteurs les atténuations totales et non-résonantes du flux incident de photons; et
v) obtenir à partir desdites atténuations l'atténuation résonante nette et sa distribution spatiale.

2. Procédé selon la revendication 1, comprenant l'étape d'interprétation de ladite atténuation résonante nette afin d'obtenir une lecture quantitative de l'azote détecté.

3. Système pour la détection d'une matière explosive asotée (6) dans un objet (5), comprenant :
i) une source (1) de rayons γ de 9,17 MeV;
ii) un détecteur de rayons γ (3) avec un milieu de détection riche en azote et destiné à indiquer les modulations du flux détecté de photons;
iii) un moyen de support pour maintenir un objet inspecté de manière à couper les rayons γ provenant de ladite source de rayons γ de 9,17 MeV; et
iv) un moyen pour balayer l'objet inspecté avec les rayons γ émis par ladite source de rayons γ de 9,17 MeV.

4. Système selon la revendication 3, dans lequel ledit moyen de support est mobile, d'où il résulte qu'un objet inspecté est balayé par les rayons γ.

5. Système selon la revendication 4, dans lequel ledit moyen de support est une bande de convoyeur (14) destinée à déplacer une suite d'objets à inspecter à travers les rayons γ.

6. Système selon la revendication 3, dans lequel la source de rayons γ et le détecteur sont mobiles en synchronisme, d'où il résulte qu'un objet inspecté est balayé par les rayons γ.

7. Système selon l'une quelconque des revendications 3 à 6, comprenant un moyen de processeur (13) pour comparer continuellement le flux détecté de photons au flux de photons émis.

8. Système selon la revendication 7, dans lequel ledit moyen de processeur est destiné à interpréter toutes les modulations du flux obtenues par balayage d'un objet.

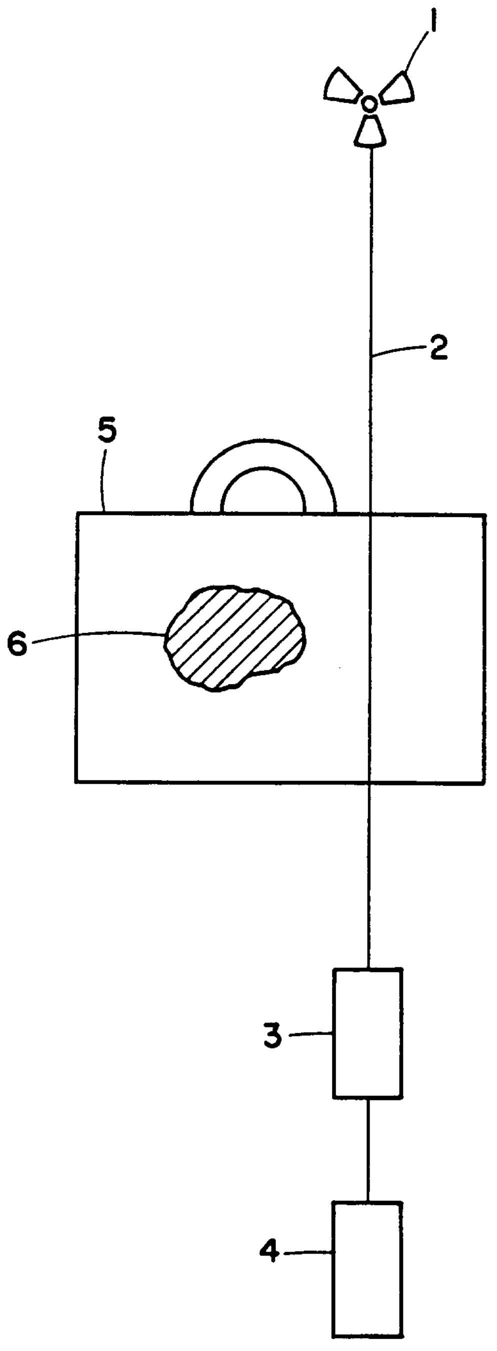

Fig. 1

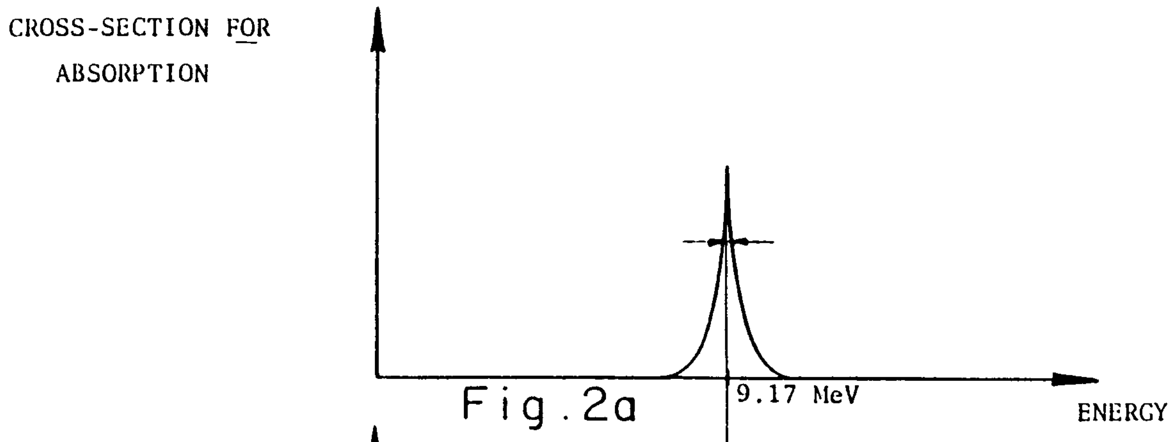

Fig.2a

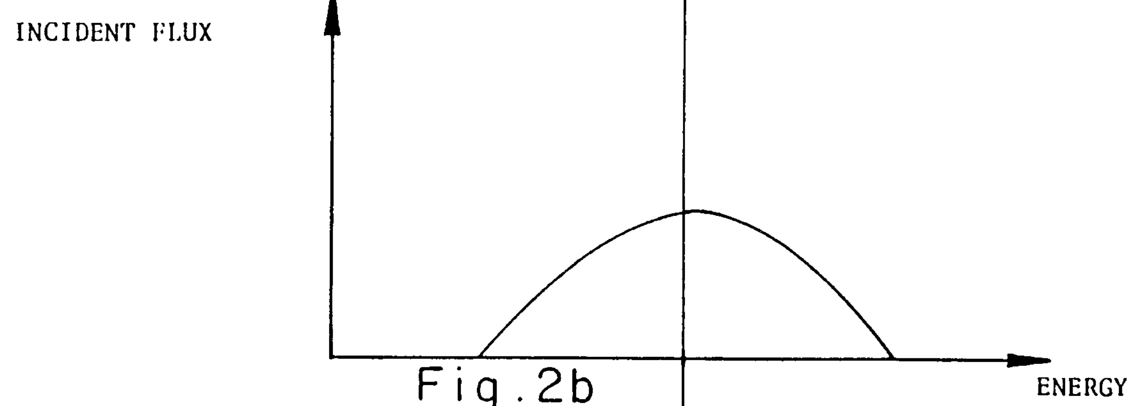

Fig.2b

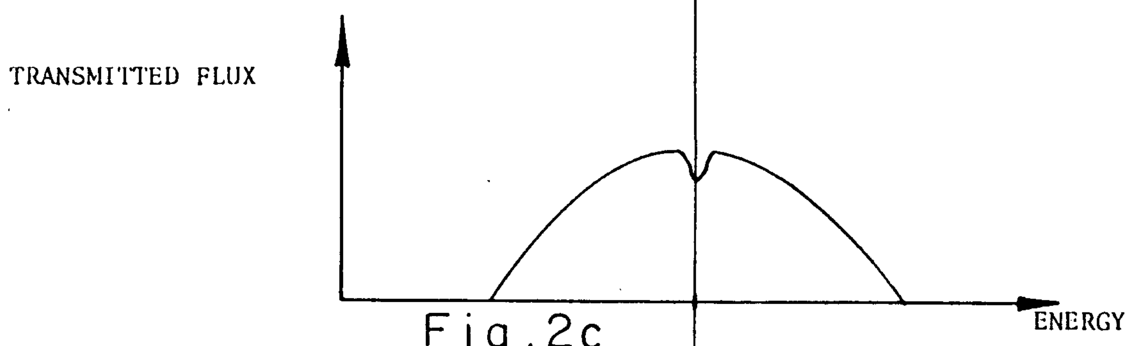

Fig.2c

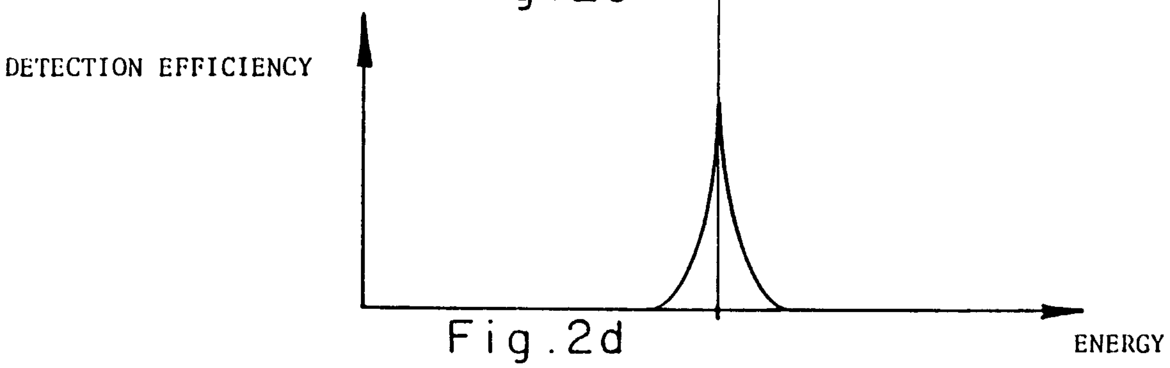

Fig.2d

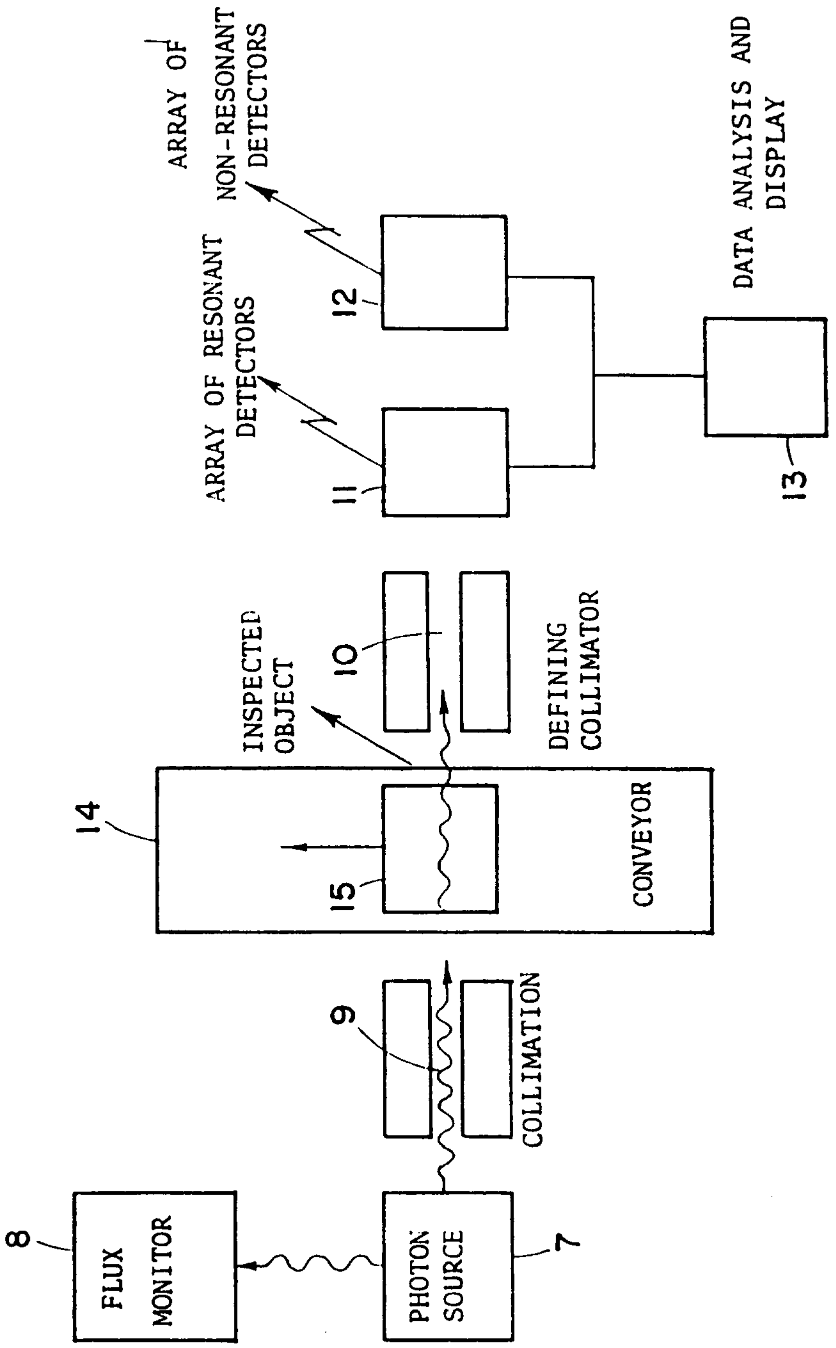
8
FLUX MONITOR
PHOTON SOURCE
7
9
COLLIMATION
14
15
CONVEYOR
INSPECTED OBJECT
10
DEFINING COLLIMATOR
11
ARRAY OF RESONANT DETECTORS
12
ARRAY OF NON-RESONANT DETECTORS
DATA ANALYSIS AND DISPLAY
13

Fig. 3

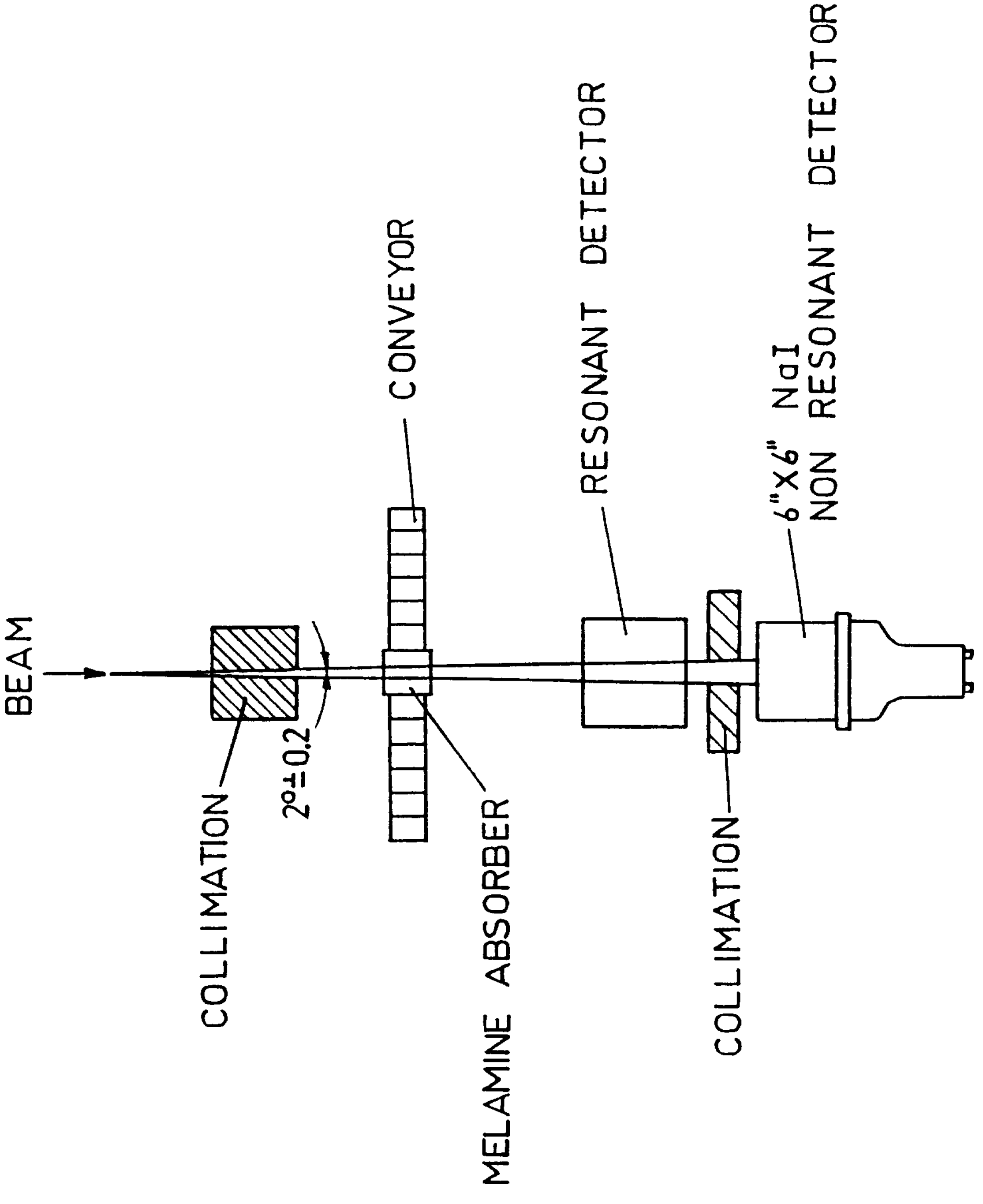
BEAM
COLLIMATION
2°±0.2
CONVEYOR
MELAMINE ABSORBER
RESONANT DETECTOR
COLLIMATION
6"X6" NaI
NON RESONANT DETECTOR

Fig. 4